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COMPARISON OF DUST SAMPLING INSTRUMENTS IN COAL AND URANIUM ORE DUST CLOUDS IN A DUST CHAMBER

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COMPARISON OF DUST SAMPLING INSTRUMENTS IN COAL AND URANIUM ORE DUST CLOUDS IN A DUST CHAMBER

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ABSTRACT

Several gravimetric respirable dust samplers were tested in a laboratory dust chamber. The Casella 10 mm metal cyclone (model T13040), the NCB-MRE 113A horizontal elutriator, and the CAMPEDS personal dust sampler were compared with the Casella Hexhlett (model 13100). The instruments were tested in pulverized coal and uranium ore dust clouds in various concentrations between 3 mg/m^3 and 15 mg/m^3.

The Hexhlett was used as a standard instrument when comparing total respirable dust measurements; for comparison of quartz respirable dust responses, the NCB-MRE 113A horizontal elutriator was used as a standard. Within the 3 mg/m^3 to 15 mg/m^3 range, a good linear relationship was found between the standard and other instruments. Linear regression analysis curves were determined to correct measurements in that dust concentration range. To correct gravimetric instruments in lower dust concentrations, calculated ratios are suggested.

Keywords: Respirable dust; Dust sampling; Instrument comparison; Calibration of instruments.

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COMPARAISON EFFECTUÉ ENTRE LES INSTRUMENTS D'ÉCHANTILLONNAGE DE LA POUSSIÈRE CONTENUE DANS DES NUAGES DE POUSSIÈRE DE CHARBON ET DE MINERAI D'URANIUM DANS UNE CHAMBRE À POUSSIÈRE

par

M.G. Grenier*, S. Hardcastle*, A. Frattini** et K. Butler**

RÉSUMÉ

On mis à l'essai plusieurs échantillonneurs gravimétriques de poussières respirables dans une chambre à poussière en laboratoire. Les instruments suivants: soit le Casella à cyclone en métal 10mm (modèle T13040), l'appareil d'élution horizontal NCB-MRE 113A et l'échantillonneur de poussières personnel CAMPEDS ont été comparés au Casella Hexhlett (modèle 13100). Les instruments ont été mis à l'essai dans des nuages de poussières de charbon pulvérisé et de minerai d'uranium à des concentrations diverses comprises entre 3 mg/m^3 et 15 m g/m^3.

Le Hexhlett a été utilisé comme instrument de référence lorsqu'on a comparé les mesures de poussières respirables totales tandis que l'appareil d'élution horizontal NCB-MRE 113A a servi d'instrument de référence lors des comparaisons effectuées avec les poussières de quartz respirables. On a constaté dans l'intervalle de 3 mg/m^3 à 15 mg/m^3 qu'il y avait une bonne relation linéaire entre les instruments de référence et les autres instruments utilisés dans le cadre de ces essais. On a déterminé les courbes d'analyse de la régression linéaire pour corriger les mesures obtenues dans l'intervalle des concentrations de poussières susmentionné. On suggère, en outre, des pourcentages déjà calculés pour rectifier les instruments gravimétriques lorsque les concentrations de poussières sont faibles.

Mots-clés: Poussière respirable; échantillonnage de la poussière; comparaison entre les instruments; instrument de mesure.

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INTRODUCTION

Gravimetric respirable dust samplers are used in underground mines to determine the time-weighted average exposure of mining personnel to respirable airborne dust. The majority of these samplers are designed to match specifications set by the American Conference of Governmental Industrial Hygienists (ACGIH), or by the British Medical Research Council (BMRC).

Because of the intrinsic differences in sampler design and of the different physical principles for removing the non-respirable fraction of dust, each type of sampler has cut sizes that vary in value as well as in sharpness. The tests performed here were aimed at comparing different types of samplers under varying conditions including dust type, size distribution and concentration.

DESCRIPTION OF DUST CHAMBER AND SAMPLING INSTRUMENTS

DUST CHAMBER

The dust chamber used for these experiments was 1.83 m high, 1.83 m wide and 2.44 m long with a total internal volume of approximately 8.2 m^3. The building material used was plywood, lined inside with 24 gauge sheet metal. The chamber was equipped with a fan used to circulate the air and dust. Two observation windows are located on one side of the chamber along with several sampling ports. The chamber is described in more detail elsewhere (1).

DUST FEED APPARATUS

The dust feed system used was of a Safety in Mines Research Establishment design. It consisted of a horizontally positioned grooved disc which rotated slowly. Dust was fed into a groove from a reservoir funnel, and scraper plates ensured that the groove was filled evenly with dust. The speed

of rotation of the disc and the size and depth of the groove determined the dust feed rate to the chamber. Dust was drawn from the groove with the option of it passing through a jet mill, which provided a finer dust cloud inside the chamber. Additional information on the dust feed system is available elsewhere (2).

SAMPLING FLOW REGULATORS

All gravimetric samplers were operated via sampling ports connected to a vacuum manifold. Sampler flows were regulated by critical orifices in all cases. The flows were calibrated against a wet test gas meter and rotameters. Table 1 lists the instruments used and the flow rates associated with each type of sampler.

Table 1 - Number of each type of instrument with related flow rates.

Instrument	Number Used	Flow Rate (L/min)
T13040 metal cyclones	4	1.9
CAMPEDS	2	2.0
MRE 113A	2	2.5
MRE 113A modified	2	1.9
Hexhlett	1	51.7
Hexhlett	1	50.0
Hexhlett	1	12.5
Hexhlett	1	4.0
cascade impactor	1	7.0

Four Casella 10 mm metal cyclones (model T13040) were used at a flow rate of 1.9 L/min. Four Casella MRE 113A horizontal elutriators were available; two were used at 2.5 L/min, and two modified versions of the instrument were used at 1.9 L/min. Two CAMPEDS personal dust samplers were

operated at 2 L/min. Four Casella Hexhlett horizontal elutriators were used at flow rates of 51.7, 50.0, 12.5 and 4.0 L/min, respectively. A Sierra (now Anderson) eight-stage cascade impactor was used to establish the size distribution of the dust cloud. A brief description of each sampler is given below.

CAMPEDS PERSONAL DUST SAMPLERS

The CAMPEDS samplers operate on inertial principles and are described at length elsewhere (3). They are designed to sample respirable dust according to the British Medical Research Council (BMRC) specifications. The non-respirable fraction is removed in the first stage of the sampler. In the second stage, respirable dust is collected on a 25 mm, 5 μm pore size silver membrane filter. This filter can be analyzed for respirable quartz dust concentration using X-ray diffraction (XRD) analysis. The sampler is operated at 2 L/min.

METAL CYCLONES (CASELLA T13040)

This gravimetric sampler was originally developed by the British Cast Iron Research Association, it was also designed to meet with BMRC standards. As with the CAMPEDS, dust is collected on a 25 mm silver membrane filter disc for analysis by XRD.

HORIZONTAL ELUTRIATOR (CASELLA NCB-MRE 113A)

The MRE 113A is also a two-stage sampler. The first stage consists of a series of parallel plates where non-respirable dust settles gravitationally. The finer respirable portion does not settle on the plates and is collected on a filter disc in the second stage.

Two types of MRE 113A were used. Two samplers were used in the original version (4 channels, or elutriating plates with 55 mm glass fiber filter discs) at 2.5 L/min, and two more were operated in a three-channel version (using 25 mm silver membrane filters compatible with XRD analysis) at

1.9 L/min).

HORIZONTAL ELUTRIATOR (CASELLA HEXHLETT MODEL 13100)

The Hexhlett sampler operates on the same physical principles as the MRE 113A, but is used at a much higher flow rate (typically 50 L/min). This allows for more dust to be collected which results in greater accuracy in the measurement of total respirable dust. For this reason, the Hexhlett was used to assess the performance of all the other gravimetric samplers tested in this comparative study.

Four Hexhlett samplers were available for the tests. Two of these were operated at the recommended 50 L/min*, and as such were true total respirable dust monitors. Two other Hexhlett samplers were used at flow rates of 12.5 L/min and 4.0 L/min, respectively. The results from the low flow rate samplers along with those from the high flow rate elutriators allowed the dust size distribution to be deduced for comparison with cascade impactor data.

CASCADE IMPACTOR (SIERRA MODEL 210)

The model 210 is a multi-stage radial slot design impactor. The size distribution is calculated from the mass of dust collected on slotted glass fiber collection substrates placed behind each stage. A flow rate of 7.0 L/min was chosen which defined cut-off points ranging between 0.3 μm and 18.0 μm for stages 8 to 1, repectively.

EXPERIMENTAL PROCEDURES

Seven experiments were conducted in the dust chamber. Three of these were coal dust experiments using crushed and pulverized coal from Nova Scotia. Four more experiments were performed, and these used uranium ore from the Elliot Lake area. This ore is known to contain 65% quartz on average. This

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*One of these was actually operated at 51.7 L/min according to an earlier flow rate calibration.

material was crushed and pulverized using laboratory apparatus.

Prior to starting the experiments, the samplers were cleaned, loaded with new pre-weighed filters and were placed inside the dust chamber. The chamber was cleaned after each run. After the door was closed, the exhaust and the circulating fan were started. The dust feed mechanism was started, and sampling began as soon as the dust concentration profile had stabilized. The duration of the sampling varied between 40 and 170 min depending on the dust concentration. Sampling times, average total respirable dust concentrations, as well as the type of dust used for each experiment are shown in Table 2.

Table 2 - Type of dust, sampling time and average dust concentration used during each test.

Test No.	Dust Type	Sampling Time (min)	Respirable Dust Conc. (mg/m)
1	Coal	105	7.5
2	"	150	2.8
3	"	146	5.1
4	Uranium Ore	106	5.6
5	" "	170	2.7
6	" "	40	16.9
7	" "	144	3.7

RESULTS AND DISCUSSION

GRAVIMETRIC SAMPLERS

Gravimetric data from the seven tests performed are listed in Tables 3 to 6. Tables 3 to 5 list the concentrations of total and quartz respirable dust (mg/m^3) for the metal cyclones, the CAMPEDS and two of the MRE 113A

Table 3 - Dust concentration data from the T13040 metal cyclones.

Run No:	CY1		CY2		CY3		CY4	
	(T)	(Q)	(T)	(Q)	(T)	(Q)	(T)	(Q)
1	8.07	0.70	9.12	0.80	8.37	0.80	8.32	0.75
2	2.96	0.17	3.20	0.25	3.03	0.18	2.83	0.19
3	5.41	0.15	5.88	0.27	5.88	0.30	5.62	0.30
4	5.91	3.33	6.36	3.53	6.16	3.57	5.96	3.43
5	3.00	1.46	3.13	1.55	3.07	1.52	2.54	1.55
6	17.63	10.39	19.61	12.11	18.95	11.71	17.89	11.32
7	3.98	2.16	4.20	2.23	4.35	2.23	3.95	2.27

Casella metal cylones (T13040); Respirable dust concentration (mg/m^3);
(T) = Total dust; (Q) = Quartz dust.

Table 4 - Dust concentration data from CAMPEDS samplers.

Run No.	C5		C6	
	(T)	(Q)	(T)	(Q)
1	8.38	0.71	7.95	0.62
2	2.88	0.23	2.94	0.16
3	5.72	0.23	5.55	0.22
4	6.37	3.35	6.32	3.16
5	3.24	1.59	3.18	1.53
6	18.86	10.88	19.13	11.38
7	4.20	2.22	4.17	2.19

CAMPEDS personal dust samplers; Respirable dust concentration (mg/m^3);
(T) = Total dust; (Q) = Quartz dust.

Table 5 - Dust concentration data from MRE 113A samplers.

Run No.	MRE 113-7 (T)	MRE 113-7 (Q)	MRE 113-8 (T)	MRE 113-8 (Q)	MRE 113-E (T*)	MRE 113-F (T*)
1	7.92	0.66	7.87	0.81	8.95	8.34
2	2.77	0.23	-	-	3.14	2.91
3	5.22	0.23	5.37	0.25	5.37	5.21
4	5.74	3.02	5.74	3.07	5.96	-
5	2.76	1.38	3.01	1.47	2.99	2.80
6	17.33	10.67	17.73	10.13	18.30	17.60
7	3.89	1.93	-	-	3.83	3.67

Casella MRE 113, Respirable dust concentration (mg/m^3)
(T) = Total dust; (Q) = Quartz dust.

*Filter substrates used in the original version of the MRE-113 are not compatible with the X-ray analysis apparatus. Thus, for these instruments only total dust data are available.

Table 6 - Dust concentration data from the Hexhlett samplers.

Run No.	HEX-A	HEX-B	HEX-C	HEX-D
1	7.75	7.27	2.77	0.81
2	2.87	2.82	1.03	0.36
3	5.19	5.08	1.85	0.51
4	5.57	5.57	3.36	1.82
5	2.72	2.71	1.71	0.84
6	16.62	17.21	8.46	4.37
7	3.76	3.75	2.33	1.28

Casella Hexhlett samplers; Total respirable dust concentration (mg/m^3)*.

*Samplers C and D were used at 12.5 and 4.0 L/min, respectively to provide data to determine the size distribution of the dust cloud. This changes the samplers' cut size so these samplers do not give true respirable dust concentrations.

horizontal elutriators. Total respirable dust concentration for the hexhlett samplers are shown in Table 6.

From the data in Tables 3 to 5, it is possible to calculate an average of 54% for the fraction of airborne respirable quartz in the dust cloud, during uranium ore dust experiments. The percentage of quartz from the CAMPEDS and the MRE 113A samplers was measured at 53% while the cyclones measured a few percent more at 56%.

The quartz content of the rock matrix is estimated at 65% for the uranium ore. The experimentally determined value of 54% for airborne quartz is lower than the matrix content, but consistent with previous measurements performed in the field (4).

The metal cyclones, CAMPEDS and MRE 113A samplers were calibrated against the Hexhlett samplers for correction of the total respirable dust concentration data. The cyclones and CAMPEDS sampler results were calibrated against data from the modified MRE 113A samplers when corrections to respirable quartz dust were made.

The two following methods of correction were used:

1. The dust concentration from the standard instruments (Hexhlett for total dust and MRE 113A for quartz) was plotted versus that of the samplers being evaluated. Regression analyses were performed on each set of points and the resulting line could then be used to correct experimentally determined concentrations.
2. Ratios from the concentration measured by standard samplers divided by that measured by tested samplers were calculated. The average of these ratios for each instrument in different types of dust clouds could also be used to correct measured dust concentrations.

The results from the regression analyses are given in Table 7. The slopes vary between 0.85 and 0.95, and the intercepts are usually low in

value, but can be as high as 0.38 mg/m^3 in the case of coal dust sampling. In every case there is very high positive correlation for the regression line.

There are some differences in intercept and slope values for a given instrument when used in different dust clouds. Conversely, there are some variations in these parameters where different samplers are used in the same dust cloud. These variations can be caused partly by differences in size distribution between coal dust and uranium ore dust. Changes in size distribution coupled with the varying degree of sharpness of cut of each instrument could account in part for the variability of results. Also the relatively small number of instruments tested, as well as experimental errors such as weighing inaccuracies, could be partly responsible.

Table 7 - Linear parameters for equations used to correct respirable dust measurements from calibrated instruments.

Dust Type	Instrument	Slope(m)	y-Intercept(b)	Corr. Coef.(R^2)
Coal	Metal cyclones	0.85	0.27	1.000
"	CAMPEDS	0.88	0.23	0.999
"	MRE 113A	0.87	0.38	0.997
U-Ore (Total)	Metal cyclones	0.91	0.01	1.000
" "	CAMPEDS	0.89	-0.08	1.000
" "	MRE 113A	0.95	0.05	1.000
U-Ore (Quartz)	Metal cyclones	0.92	-0.06	1.000
" "	CAMPEDS	0.94	-0.07	1.000

Note: The correction equation uses the slope and y-intercept from the above table as follows: Corrected value = m x measurement + b, (mg/m^3).

The regression line correction is only valid to accurately correct dust concentration measurements in the 3 mg/m^3 to 15 mg/m^3 range (the range over which the experiments were conducted). Linear regression adjustments should not be used for concentrations outside this range. This is especially true in

the case of low dust concentrations, where a large intercept value (e.g., for coal) could lead to sizeable discrepancies.

The second type of correction that can be applied involves the ratios mentioned earlier. Table 8 shows the average of these ratios for different instruments used in different types of dust clouds. Differences in ratio values can be attributed to reasons similar to those mentioned above for the regression analysis.

Table 8 - Ratios used to correct respirable dust measurements from calibrated instruments.

Dust Type	Instruments		
	Metal Cyclone	CAMPEDS	MRE 113A
Coal	0.91±0.03	0.94±0.05	0.94±0.04
Total U-Ore	0.90±0.02	0.88±0.02	0.96±0.02
Quartz U-Ore	0.90±0.03	0.91±0.03	

Note: Correct the instrument reading by multiplying by the above appropriate ratio.

A Student-t test was performed on each average ratio from the tested sampling instruments to try to determine the 95% confidence interval of a total sampler population. These confidence intervals are also shown in Table 8. The intervals show that for coal, there is no evidence to indicate that it is possible to differentiate between any of the correction ratios associated for the three samplers tested. This is caused mostly by the higher degree of variability of data during coal tests.

For uranium ore dust, the confidence intervals overlap for both total and quartz respirable dust in the case of the cyclones and the CAMPEDS. The MRE 113A, however, seems to have a ratio that is distinctly higher than the other two samplers.

Correction ratios should be used on data from tested samplers for concentrations outside the 3 mg/m^3 to 15 mg/m^3 range. For simplicity, the ratios could even be used within this range. In the worst instance encountered during these tests (MRE 113A calibrated with Hexhlett samplers in coal dust), using ratio correction as opposed to the linear regression approach could lead to a maximum discrepancy of 5.4%.

SIZE DISTRIBUTION MEASUREMENTS

Size distribution measurements of the dust cloud were performed during tests 1, 2, 3, 5 and 7. The mass-median aerodynamic diameter (MMAD) and the geometric standard deviation (σ_g) were measured using an 8-stage cascade impactor, and results were compared to those obtained by a method described by Knight (5). This method involves the use of at least two size-selective samplers (Hexhletts) operating at different flow rates. The total airborne dust concentration as measured by an open filter is also needed to carry out the analysis. The total mass collected by the Sierra impactor was used to calculate this parameter. Results of size distribution measurements are given in Table 9.

Table 9 - Dust cloud size distribution as measured by Hexhlett samplers used at different flow rates, and by Sierra cascade impactor.

Test No.	Hexhlett Size Dist. MMAD (μm)	σ_g	Sierra Impactor Size Dist. MMAD (μm)	σ_g
1	6.0	2.3	5.4	2.2
2	5.3	2.2	5.2	2.2
3	5.0	2.0	4.9	2.1
5	2.0	1.8	2.3	2.6
7	3.3	2.4	3.3	2.1

Some statistical tests were performed on the averages of MMAD and σ_g for both methods in each type of dust cloud. These tests show that at a 95% confidence level, the average values of MMAD and σ_g are the same for both methods irrespective of the test being conducted in coal dust and uranium ore dust clouds.

CONCLUSIONS

Gravimetric sampler concentration measurements may be corrected by using the regression formulae given in Table 3 within a dust concentration range of 3 and 15 mg/m^3. For concentrations lower than 3 mg/m^3, correction ratios should be used in place of regression formulae. Correction ratios may also be used within the above range without introducing unreasonable error (<6%).

Size distribution measurements showed that the coal dust used in these tests had a larger MMAD value than the uranium-ore dust. The geometric standard deviation is similar for both dust types. It was possible to show statistically that both methods used to establish the dust size distribution gave similar values of MMAD and σ_g for both coal and uranium-ore dust.

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